AUTOMATED CHARACTERIZATION OF FIBER OPTIC DETECTORS

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CERTIFICATE

This is to certify that this thesis, entitled "AUTOMATED CHARACTERISATION OF FIBER OPTIC DETECTORS" by Miss S. A.P.L.Kumari (Roll No.9412406) has been carried out under our supervision and that it has not been submitted elsewhere for the award of a degree.

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ABSTRACT

For designing fiber optic systems, it is necessary to know the transfer characteristics of sources (LEDs,Laser diodes) and photo detectors(PIN/ APD diodes).

In the present work, we have tried to plot automatically the characteristic curves for sources and detectors to reduce the time consumed for manual plotting.

The characteristic curves which we have plotted using this automated method are found to be almost linear, but, near the origin and middle of the characteristics non linearity can be observed. The reason for this non linearity could be due to the effect of cumulative non linearities of each sub system in the automated set up.

DEDICATED TO

MY PARENTS

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S.A.P.L.KUMARI

CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Fiber optic system is an optical transmission system that uses glass or plastic fiber for transmitting the optical signal. Light entering at one end of the fiber with a certain solid angle undergoes total internal reflection at the surface and is transmitted through the fiber. There is no electromagnetic induction possible in optical fibers, so these are used in areas where electric isolation and interference are severe problems.A basic fiber optic source consists of optical transmitter, a fiber and an optical receiver shown in Fig. 1.1 [1].

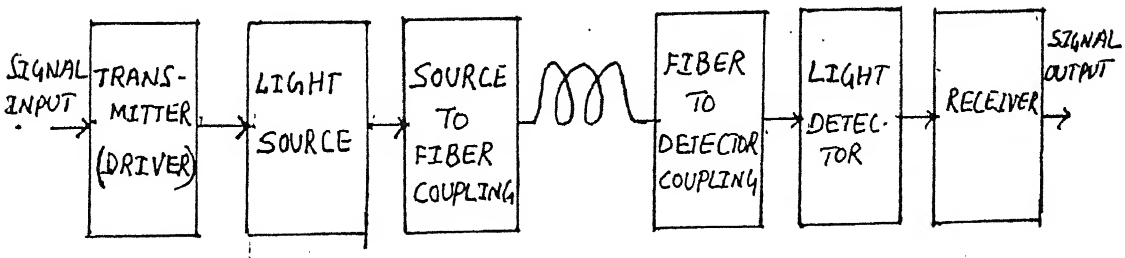


Fig. 1.1 : basic fiber optic communication system

The optical transmitter converts electrical pulses into pulses optical power. The fiber captures some fraction of the power emitted by the transmitter and transports it to the receiving end of the fiber link. The optical receiver converts the pulses of optical power emerging from the fiber into electrical

pulses. Optical power can be modulated by modulating the electric current that supplies light emitter.

The implementation fiber optic system requires reliable, economical optical sources as emitters at the appropriate wavelength with a suitable input output characteristics, and optical detectors having high sensitivity.

The input current to output power ratio is a system design parameter of a semiconductor light source. It defines the drive current needed to generate the optical output power.The choice of a particular light source for a particular system determines the electronic drive circuit needed to amplify the input signal to the required level, to drive the light source. It also determines the optical power available from the source for coupling to the fiber.

A suitable source for an optical fiber communication system must have certain characteristics like emission of light at a wavelength within a window of low fiber transmission loss, efficient conversion of input power to light coupled to the fiber ana low noise,high linearity modulation, high reliability, effective radiating area, sufficient narrow spectral width etc. The principal light sources used are injection laser diodes (ILDs) and light emitting diodes (LEDs).

When a semiconductor device is constructed such a way that only spontaneous emission takes place,the device is refereed to as a light emitting diode.this device emits radiation within a relatively narrow spectral region and with sufficient output power and good power conversion efficiency which is useful for fiber optic system [2].

Laser is a light source in which the output involves the process of stimulated emission. Laser emit radiation with high degree of coherence compared to LEDs some lasers will produce very large power in a narrow spectral range.The characteristics of semiconductor lasers are better suited for fiber optic communication systems, hence generally used.

LED is not temperature sensitive it can operate large temperature range compared to laser.It is suitable for analog transmission as its output is approximately proportional to the driving current.For pulse modulation systems laser produces high data rates and it couples more power than LED [3].

Detector is an essential component optical fiber communication system and it is one of the important element for the overall performance.A photo detector senses the optical power incident on it and converts it to corresponding electrical current, i.e. performance is expressed as a transfer parameter which is the ratio of the electric current generated at the detector output to the optical power applied to the detector in ampers per watt, which is known as the responsivity of the detector. Photo detectors for application in communication system should have a high responsivity in the particular spectral region, low dark current, and high speed of response.Two types of photo detectors PIN photo diode and Avalanche photo diode satisfies these requirements, so they are generally used in fiber optic links.

A PIN photo diode is simpler, stable with changes in temperature, and less expensive than a Avalanche photo detector.

detector. PIN diodes require less bias voltages.(50V compared to to several hundred volts of APD). But the APDs will have high sensitivity compared to PIN diodes.

For characterizing sources and detectors the spectral response(which gives the range of wave length in which the device operate), linearity and V-I characteristics of the devices must be known.

For manual plotting of these characteristics, for example incident radiant energy versus photo current in micro ampers for a detector a photometer is used.The basic photometer unit consists of a light detector, an amplifier,either analog or digital display,function selector switch. A suitable filter also used depending upon the wave length region in which the measurement is carrying out. For illumenence measurement. Selector switch is to micro watts. Light from the source like is exposed to the photo sensitive surface of the light detector which is a silicon PIN diode. Then the irradiance i.e radiant flux density in micro watts directly displayed on the meter. The PIN diode converts light energy into an electrical current. The current is proportional to intensity of the incident light beam and varies with its wave length. The electrical current is amplified, amplified output current is then observed using an ammeter by keeping function selector switch in μA's. Characteristic curve is plotted between optical power input vs photo current.

The experimental procedure explained above is a tedious process which can be simplified using automation of the test set up. The automated set up consists of DAC source driver detector

circuit and ADC. The DAC gets input from the personal computer through a 8 bit parallel port. The output of this converter is applied to a source driving circuit. The output of the source is then detected by the detector circuit and fed to an ADC and this digital output is given to the computer for further processing.

ORGANIZATION OF THE THESIS:

The thesis has been organized into four chapters. A brief review of fiber optic sources and detectors is given in the second chapter. The third chapter describes the experimental setup for the automated characterization of sources and detectors. The results, discussions and conclusions are given in the forth chapter.

CHAPTER - 2

FIBER OPTIC SOURCES AND DETECTORS

Any device which acts as either light source or light detector has to satisfy some predefined characteristics for efficient transmission or detection. Characteristics curves which define the performance of these devices, and their details are dealt briefly in this chapter.

2.1 SOURCES

The light sources for fiber optics must be monochromatic if possible. Most light sources are not single frequency but emit light at several frequencies over a band. A few sources such as gas ionization lamps, light emitting diodes and lasers emit light over a much narrower portion of the spectrum even though these are not truly monochromatic. The other requirement is that sources should have a high intensity of light output, so that sufficient energy is transmitted to overcome the losses encountered during transmission. The light sources should also be capable of being easily modulated and also must be easily coupled to the fibers.

LEDs and lasers are well suited as fiber optic sources because of their narrow spectral width, small size and direct modulation capability.Because of their small size they have higher coupling efficiency as compared to other light sources. They emit length coinciding with regions of lower attenuation in fibers [4].

2.1.1 LED

LED is an electroluminance device i.e,emission of light by application of current through the diode. LED light is due to the radiative recombination of holes and electrons. It is a forward biased P-N junction device. The requirements of an LED are high

radiative efficiency, fast emission response time, highquantum efficiency etc. For high radiative efficiency, a direct band gap semiconductor has to be used for electroluminance devices.In direct band gap semiconductors the electrons and holes have the same value of momentum on either side ofthe forbidden energy gap, so direct recombination is possible

LED is formed by the diffusion of P type donors into an N type substrate. light is emitted within the junction zone near the surface of the chip and escapes in random directions through the surface. A forward biased LED is shown in Fig. 2.1.

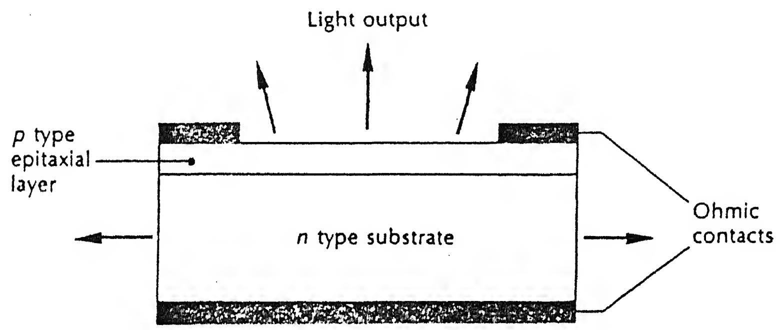


Fig. 2.1 : Forward biased LED.

LED TYPES

There are two types of configurations in LEDs in order to achieve carrier and optical requirements. They are homojunctions and single and double hetrojunctions, in which latter being the most common one. Cross section of a double hetrojunction edge emitting LED is shown in Fig. 2.2.

The two types of LED structures commonly used in fiber optics are surface emitting diode and edge emitting diode. In surface emitters the plane of the active light region is oriented perpendicularly to the axis of the fibers. The edge emitter consists of an active junction region between two guiding layers which directs the optical radiation. In this the propagating light is emitted at one end face only due to a reflector on the other end face and an anti reflection coating in the emitting end face. The active life time in both types the active layer is heavily doped with Zn to reduce the minority carrier life time. In both types the active layer regions is determined primarily by the pattern of current flow through the active layers.

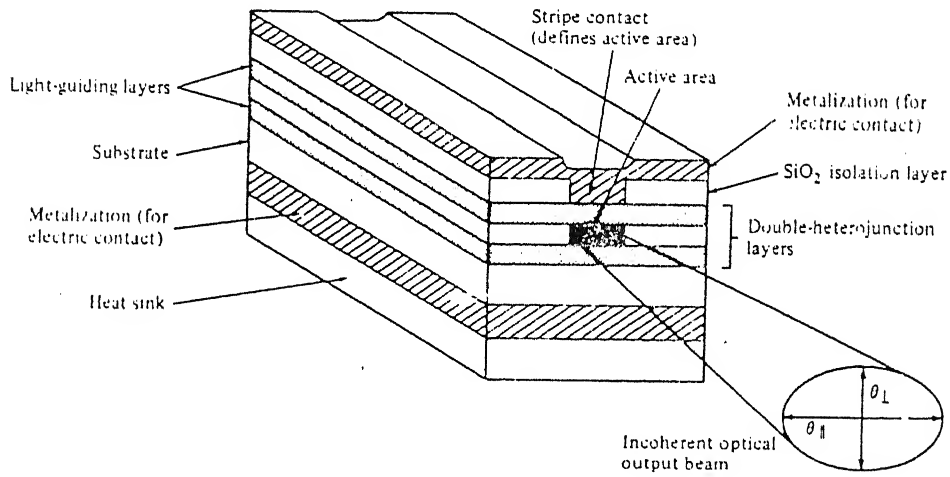


Fig. 2.2 : Cross section of an double hetro junction edge emitting LED

LED MATERIALS

The materials used for LED are Gallium Arsenide phosphide [GaAsp], Gallium phosphide [GaP], Gallium Aluminnium Arsenide [GaAlAs], Gallium Arsenide [GaAs]. LEDs are mainly made from the

compcunds of group 3 element such as (Al, Ga and In) and group Velements such as (P, As or Sb).

MOUNTING LEDs

LEDs comes in standard sizes such as T1,T1 3/4 sizes. These numbers relate to the diameter of the lamp in eights of an inch. Most lamps have plastic lenses or hermetically sealed glass. There are so many ways to mount an LED which depends on the shape, size and use of an LED . They may soldered directly on to PC boards, plugged in pre assembled sockets,In panel mounting or may be mounted with clips.

INFRARED LED

Typical infrared LED is made from Gallium arsenide (GaAs). This is a very good material to make the LED diode because most of the material's energy is given up in the form of radiant energy. With forward bias the diode emits a narrow wave length of around 900nm.

LED CHARACTERISTIC CURVES

The main characteristics of an LED are as follows :

(i) Forward current vs Output power

The characteristic is plotted between current (mA) against average output power in μw as shown in Fig. 2.3(i). It is a fairly linear curve, except for the extremes of the curve which means, a direct change in power for increments of current.

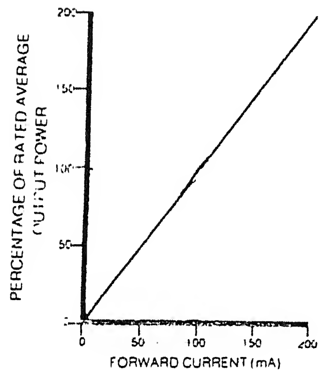
(ii) Diode voltage (in volts) vs. current (in mA)

V-I characteristics are plotted for both forward as well as reverse voltage, versus current shown in Fig. 2.3(ii). As voltage increases in the forward bias direction, current does not flow till a certain voltage is reached (approximately 1.3 volts for GaAlAs). after this voltage current increases linearly with

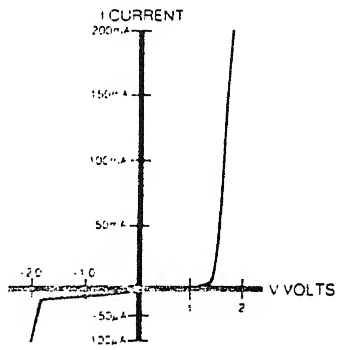
voltage.when reverse biased a very small current only flows up to a certain voltage (typically -1.9 volts for GaAlAs) is reached. After that the current will increase rapidly damaging the LED permanently.

(iii) Spectral Response Curve

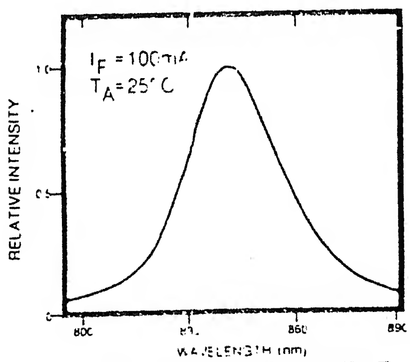
This curve is plotted between wavelength in nanometers against relative intensity as shown in Fig. 2.3(iii). For a LED operating in the infrared region the spectral width is around 40 nanometers. Which is from 825 to 865 nanometers [5].



OUTPUT POWER VS DC FORWARD CURRENT



TYPICAL I-V CHARACTERISTICS



TYPICAL SPECTRAL OUTPUT

Fig. 2.3 : LED characteristic curve

2.1.2 SEMICONDUCTOR LASER DIODES

Semiconductor injection laser diode is preferred over the LED. Laser diodes typically have response times less than 1 nanoseconds have spectral width of 2 nanonmemter or less and are capable of coupling several milliwatts of useful luminant power into optical fibers.

When a current is passed through a laser diode junction, light is emitted by spontaneous emission at a frequency or wave length determined by the energy band gap of the semiconductor material.When a certain critical current level is exceeded, the population of minority carriers on either side of the junction and the density of photons reaches such a level that photons begin to collide with already excited minority carriers. The collision causes a slight increase in the ionization energy level so that it recombines at a higher level and so two photons are released each with the same energy. In this way each photon originally released by spontaneous emission may trigger several other photons which creates an avalanche effect and so the efficiency of emission rises exponentially with current above the threshold value. Cross section of double hetrojunction semiconductor laser shown in Fig. 2.4.

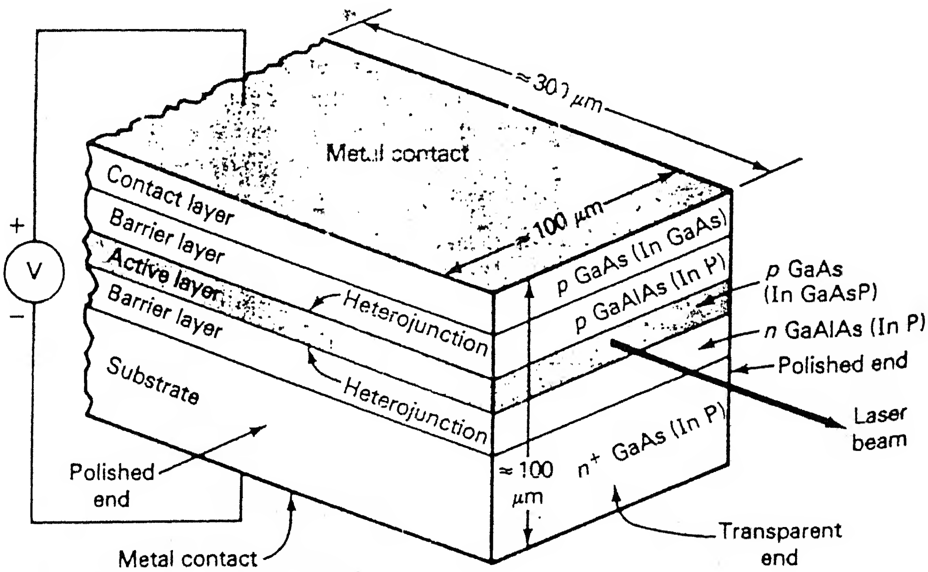


Fig. 2.4 : Crosssection of double hetrojunction semicontor laser.

Stimulated emission by the recombination of the injected carrier is encouraged in this type of lasers by the provision of an optical cavity in crystal structure in order to provide the feed back of photons.The advantages of injection lasers over the other semiconductor sources are high radiance, modulation capabilities extending upto GHz range, good spectral coherence etc. It is also called as injection laser diode (ILD) because of p-n junction.

CHARACTERISTIC CURVES

i) Output Power vs Current

An idealized optical power in milliwatt against current in milliampers characteristics is shown in Fig. 2.5(i). The solid line represents the laser characteristics whereas the dashed line is a plot showing the current threshold. After the threshold value the light output increases substantially for a small increase in current through the device. This corresponds to the region of stimulated emission when the laser is acting as an amplifier.

ii) Spectral Response Curve

It is plotted between wave length in nanometers against relative intensity. Fig. 2.5(ii) shows the spectrum for a single mode injection laser. It has a peak at 1.55 μm.[6]

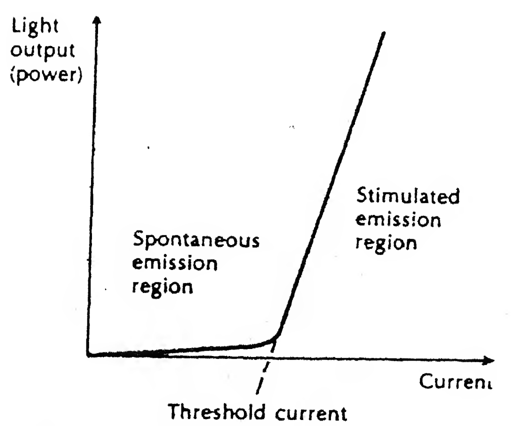


Fig. 2.5(i) : Laser characteristics.

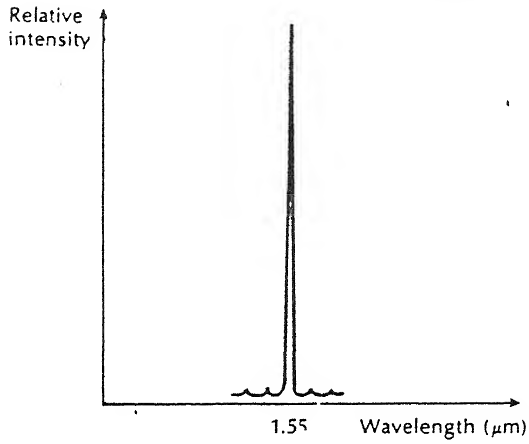


Fig. 2.5(ii) :Laser characteristics.

MATERIALS USED FOR LASER

Material used for single hetrojunction laser are GaAs/AlGaAS, GaAs/InGaP, AlGaAs/AlGaAs, InGaAs/InGaP, GaAsSb/GaAlAsSb, GaAlAsSb/GaSb and for double hetrojuction AlGaAs/GaAs/AlGaAs is used.

2.2 DETECTORS

Photo detectors are used for converting optical signal into an electrical signal.The requirements of photo detectors are high sensitivity at operating wavelengths, large electrical response to the received optical signal, short response time, minimum noise etc. Responsivity and quantum efficiency are important photo detector performance characteristics.

$$\text{Quantum efficiency } \eta = \frac{r_e}{r_p} = \frac{\text{no. of electron collected}}{\text{no. of incident photons}}$$

The responsivity of a photo detector is principally determined by the construction of the detector and type of material used.

$$\text{responsivity} = \frac{i_p}{P_o}$$

where i_p is primary photo current in amperes

p_o is incident optical power in watts

$$r_p = \frac{p_o}{hf}$$

where hf is energy of photon

$$i_p = qr_e = q\eta r_p = \frac{q\eta p_o}{hf}$$

$$R = \frac{q\eta}{hf}$$

$$= \frac{q\eta\lambda}{hc}$$

TYPES OF PHOTO DETECTORS

Main types of photo detectors are photo resistor, single junction photo diode and photo transistor. Photo resistor is a small slice of photo conductive material whose resistance increases or decreases when light energy applied. single junction photo diode is an optical version of standard diode. In this photons of light energy are absorbed into the device and electron hole pairs are generated. The current flow is dependent on the amount of radiation absorbed. These diode operate in the photoconductive mode with dc bias and in the photo voltaic mode without bias.Photo transistors are two junction devices with large base area. The base region of photo transistor absorbs the photons of energy and generates hole-electron pairs in the large base-collector region. Other type of detectors are photo field effect transistors, photo thyristors and photo isolators.

To detect optical radiation in the near infrared region of the spectrum, semiconductor photo diodes with internal gain like Avalanche photo diode or without internal gain like p-n photo diode and p-i-n photo diode.are used

2.2.1. P-N PHOTO DIODE

Ordinary p-n diode can be used as photo detector in reverse bias. It has a thin p layer deposited on an n substrate. The light enters through p layer. The diode has relatively thin depletion zone around the junction when it is reverse biased. Photons of light entering the depletion zone ionize hole-electron pairs when the encounter atoms in the depletion zone. The hole electron pairs are drawn across the junction by the reverse biased electric field contribute leakage current which is proportional to the incident light intensity. For a practical photo diode the best responsivity and highest quantum efficiency are obtained in a material having band gap energy slightly less than the energy of photons.

PHOTO DIODE MATERIALS

Silicon, Germanium, Gallium Arsenide, Indium Gallium Arsenide Phosphade ,Indium Gallium Arsenide are used for photo diode.

2.2.2 PIN PHOTO DIODE

In order to allow operation at longer wavelengths where the light penetrates more deeply into the semiconductor material a wider depletion layer is needed. To achive this n type material is doped so lightly that it can be considered intrinsic and to make a low resistance contact a highly doped n type layer is added. This creates p-i-n structure as shown in Fig. 2.6. The intrinsic layer is made thick enough so that most of the photons which pass through the junction are absorbed within the layer. the holes created within this region are swept across the junction by sufficiently large reverse bias voltage and the electrons are swept out into the n region, thus adding to the total photo current. When an incident photon has an energy greater than or

equal to the band gap energy of the semiconductor material the photon can give up its energy and excite an electron from the valence band to the conduction band which will result large photon current and thus increases the sensitivity of the diode. But since the carriers have to travel a greater distance to be removed from the depletion zone, the response time of the PIN diode is slower than that of the pn diode.

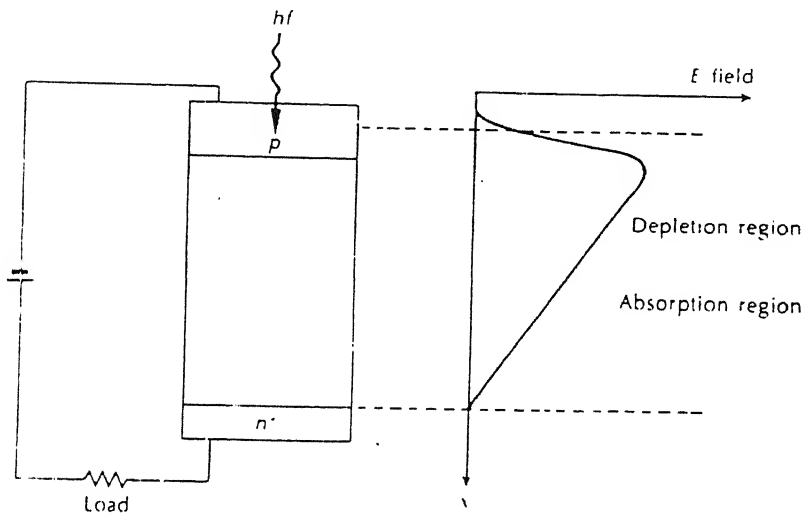


Fig. 2.6 : PIN photo diode

CHARACTERISTIC CURVES

(i) Spectral response curve

Spectral response is based on the photo diodes ability to absorb photons of light energy. This curve is plotted between resposivity of the diode in ($\mu A/\mu W$) against wave length in microns as shown in Fig. 2.7(i).

(ii) Linearity curve

A curve that is useful for study of operation of the photo diode is linearity curve. 'This curve compares incident radiant energy in watts with photo current in microampers. The curve is extremely linear when the photo diode is exposed to the radiant energy, valence electrons relased. The greater the radiant energy exposed, the greater the current flow. It is shown in Fig. 2.7(ii).

(iii) V-I characteristics

This characteristic curve is representative of both photo voltaic and photo conductive operation. Photo voltaic region of bias voltage is at zero bias with the photo diode generating the load voltage. This is called voltage mode. Photo conductive region requires constant reverse bias it is called the current mode. Current is extracted as a measure of applied radiant energy. The curve is plotted between bias voltage in order of volts against photo current in microampers as shown in Fig. 2.7(iii).

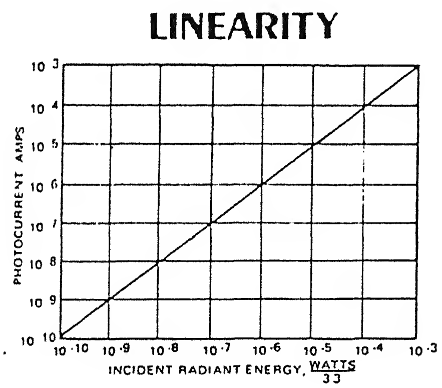


Fig. 2.7 : PIN photo diode characteristics

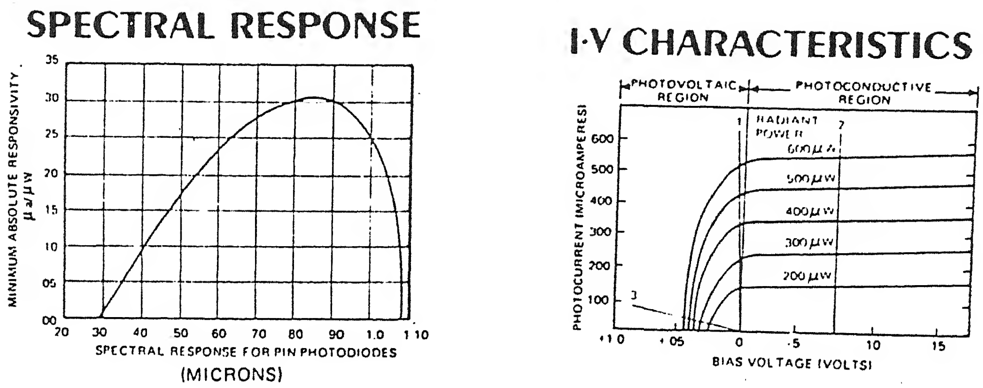


Fig. 2.7 (ii) & 2.7 (iii) : PIN photo diode characteristics.

PIN DIODE EQUIVALENT CIRCUIT

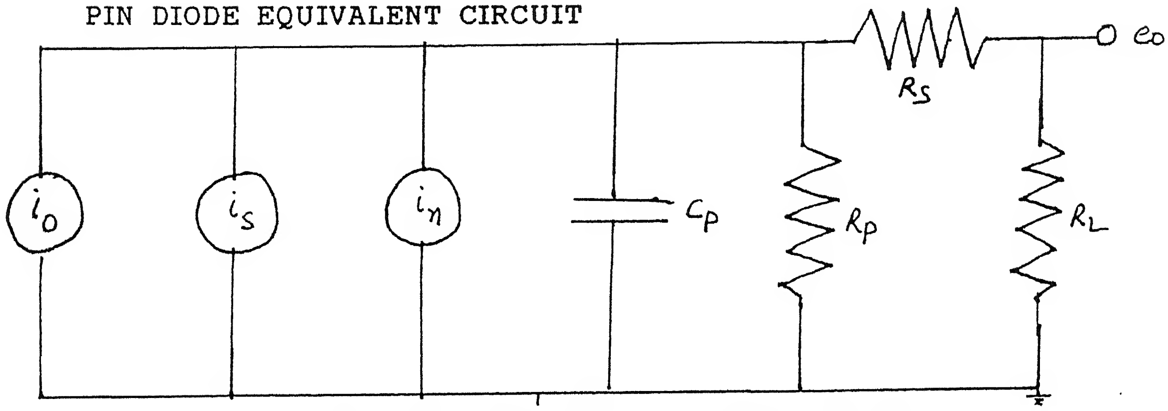


Fig. 2.8 : PIN diode equivalent circuit

Equivalent circuit is shown in Fig. 2.8. Dark current i_o is causes by reverse bias. Signal current i_s is the current developed by input light. Noise current is varies with the bandwidth, temperature and dark current. An important ratio for design is signal to noise ratio (i_s/i_n). For better design, it should have a high value.

$$e_o = (i_s + i_n + i_o)\, R_L$$

where i_s = signal current = $I_L R$

I_L = input light in watts

R = responsivity (ampers per watts)

i_n = noise current = $\sqrt{2ei_o B}$

C_p = barrier capacitance

R_p = barrier resistance

R_L = load resistance

MATERIALS USED

For shorter wavelength silicon and for longer wavelength germanium, InGaAsP, GaAlSb, InGaAs, GaSb and GaAsSb are used.

2.2.3 AVALANCHE PHOTO DIODE

This type of diode have high internal gain which obtained through a process of avalanche multiplication. This diode has sophisticated p-i-p-n structure in order to create an extremely high electric field region. In this structure light enters the diode through a thin n layer which is heavily doped and which forms one side of an abrupt junction with a thin p layer between it and an intrinsic layer. This abrupt junction drops most of the terminal voltage and generates high field needed for avalanche in the junction region under reverse biased conditions. Light which is absorbed in the i-type region to the right of junction (6) produces electron-hole pairs the electrons of which drift into the high field region. The field levels in the high field region are sufficient cause moving carriers to suffer ionization collisions for the production of additional hole electron pairs. Carriers produced by ionizing collisions plus the

original photo generated carriers in turn produce further pairs to results in a carrier multiplication. This process is called Avalanche multiplication. APD with field distribution pattern is shown in Fig. 2.9.

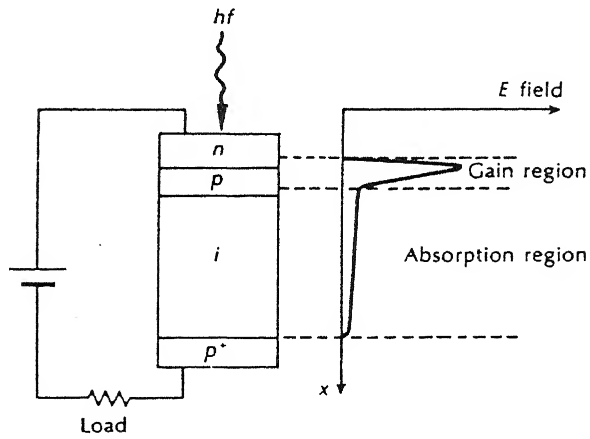


Fig 2.9. Avalanche Photo diode

Commonly used structure for achieving carrier multiplication is the reach-through construction which is composed of a high resistivity p type material deposited as a eptixial layer on a p^+ substrate. A p type diffusion is then made in the high resistivity material followed by the construction of an n^+ layer.

MATERIALS USED

Materials used for the APDs are silicon, InGaAs/InP, InGaAsP/InP, germanium for both short and longer wavelengths.

CHAPTER III

AUTOMATED CHARACTERIZATION OF DETECTORS

The automated test set up for measuring the characteristics of fiber optical detectors are shown in Fig. 3.1. As shown the set up consists of a Digital Analog Converter, Source and Source Driving Circuit, Detector Circuit and an Analog to Digital Converter.

3.1 DESCRIPTION OF THE SYSTEM

The digital to analog converter (DAC) is used for the conversion of the input digital data into a corresponding analog voltage. The input digital data is obtained from the parallel I/O port of the Personal Computer applied through CMOS buffers 2 Nos. of CD-4050 HEX CMOS buffer chips are used for proper interfacing. In order to avoid loading due to next stages like LED driver etc., the output from the DAC converter is taken from an op-amp unity gain source follower (LM324N used here to avoid dual supply voltages VCC and VEE) which acts as a buffer. . The output from the digital to analog converter is applied to a LED driver circuit which is a voltage controlled current source. Light emitted from LED varies according to the voltage input to the VCCS. The light emitted from the LED illuminates the sensitive surface of a photo detector. Depending upon the responsivity of the photo diode a corresponding current flows through the load resistance R_L which is connected in series with the photo diode. Both LED and detector are placed in such a way that the maximum emitted light from the

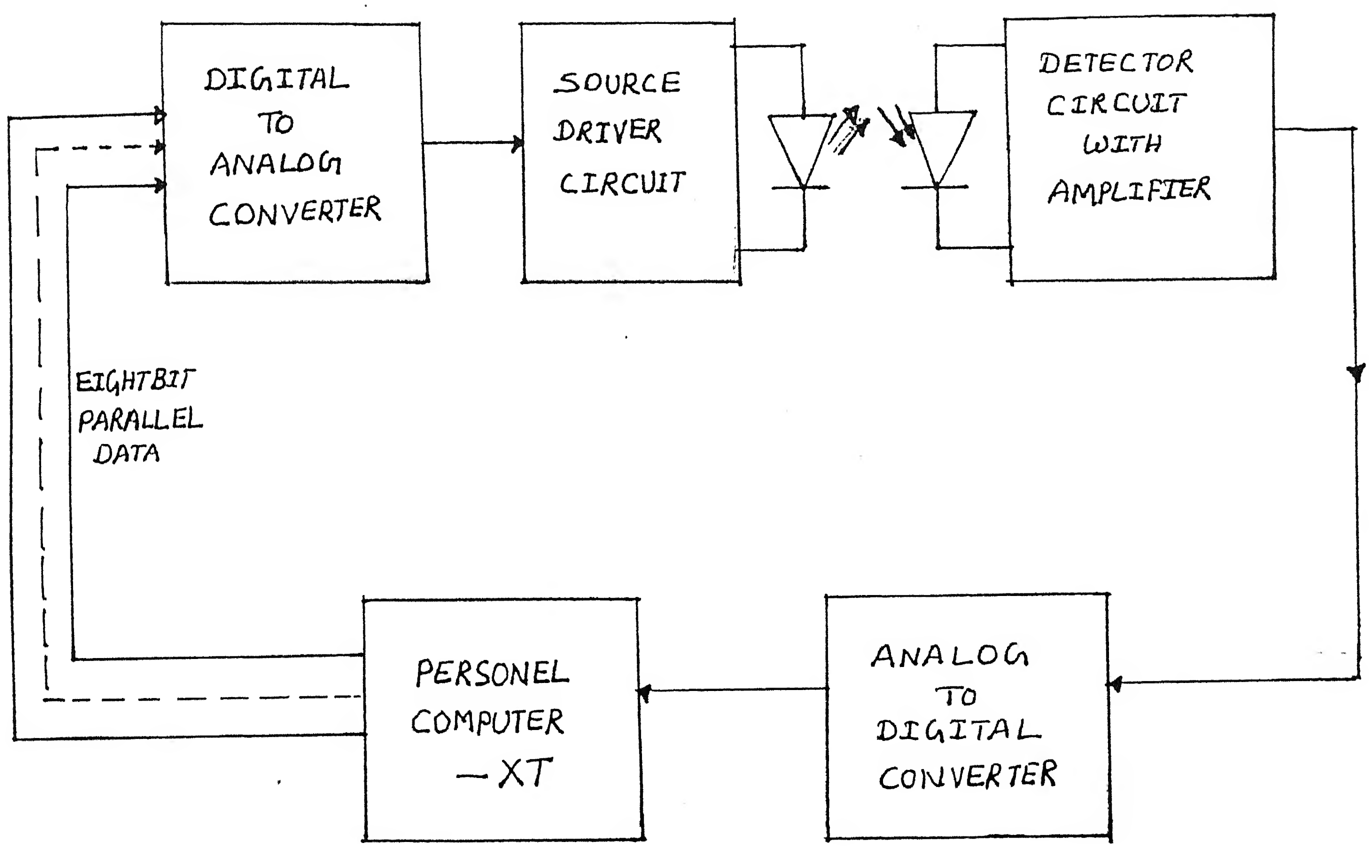


Fig. 3.1 : Automated set up

LED falls on the detector. The voltage drop across the load resistance is amplified before applying to the analog to digital converter to reduce the effect of noise at low input levels, An amplifier with the gain of 15 was used. The amplifier is used in MC1458 op-amp with a non-inverting mode. The amplifier output is applied to an analog to digital converter. The output from the ADC was read by personal computer. The procedure is repeated for a number of steps by incrementing the digital data input. The output of the D/A converter varies from zero to full scale voltage with an increment of step size which is equal to LSB. The output from the D/A converter is a staircase waveform. For each incremented value of the digital data the output from the ADC is read by the PC and stored in a specified memory location. The overall process is controlled through a software. The analog values read from PC are tabulated with the corresponding digital data, at a specified memory location. Source and detector characteristics are plotted using this data.

The details of the sub systems are described below.

3.2 DIGITAL TO ANALOG CONVERTER

The digital to analog converter accept a digital word as input data and convert it to an analog voltage or current. The digital input word can be in pure binary or binary coded decimal (BCD) format. The two commonly used types of D/A converters are (i) D/A converter with binary weighted resistors and (ii) D/A converter using a R-2R ladder network. Because of range and tolerance problems of different values of resistors, the use of weighted resistor D/A converter is limited [7].

In this set up, voltage mode R-2R ladder network is used as a D/A converter. The resistors have only two values and range problem is eliminated and to minimize tolerance problem resistors having identical characteristics are used. For number of input bits the R-2R ladder network divides the current much more accurately than by a binary weighted resistor network. If the output of D/A converter is taken through a inverting operational amplifier this becomes a current mode DAC. In voltage mode DAC the output is taken from an unity gain source follower.

The voltages at nodes of an R-2R ladder network forms a binary weighted sequence V, V/2, V/4 .... $V/2^n-1$. For obtaining this, the series resistances must have a 1:2 ratio with the shunt resistances.

3.2.1 Current mode DAC

In this mode of operation, the output voltage of R-2R ladder network are taken from an inverting current to voltage amplifier, i.e., the analog output voltage is equal to the negative of the input current multiplied by the feedback resistance value. For a R-2R ladder the connecting point is virtually at ground potential. In this configuration the R-2R ladder network produce a current that is a binary weighted sum of the node currents, $I_1 = V/2R$, $I_2 = V/4R = I_1/2$, $I_3 = V/8R = I_1/4$ ..... $I_N = I_1/2^n-1 = V/2^n$. The operational amplifier multiplies these current by a factor of $-R_F/R$.

$$V_A = -R_F/R\left(V/2R + V/4R + \ldots\ldots + V/2^n\right)$$

or $$V_A = \frac{V_o 2^0 + V_1 2^1 + V_2 2^2 + \ldots\ldots + V_{n-1} 2^{n-1}}{2^n}$$

where V_o, V_1, V_2, V_{n-1} are the digital input levels.

3.2.2 Voltage mode DAC

For avoiding variations of R-2R ladder voltage due to loading, the output voltage is taken through a unity gain high impedance non-inverting amplifier (source follower) which acts as a buffer. Then the D/A converter is said to be operating in the voltage mode. The output voltage ranges from zero to full scale in steps of $V/2^n$ or LSB.

$$V_A = \frac{V}{3}\left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \ldots\ldots + \frac{1}{2^{n-1}}\right)$$

where V is the reference supply voltage.

The key specifications for the D/A converters are resolution, accuracy, nonlinearity and settling time. Resolution defines the smallest increments in input voltage that can be disorned. It is mainly a function of number of bits in the input signal. Accuracy of the D/A converters depends mainly on the precision resistors used in the ladder and the stability of the voltage of the voltage source.After a digital input voltage is applied D/A converter takes certain time to produce the correct output, the settling time is defined as the time it takes for the converter to stabilize within ±1/2 LSB of its final value. Non-linearity is the difference between the actual output of the DAC and its ideal straight line output. It is normally expressed as percentage of the full scale value.

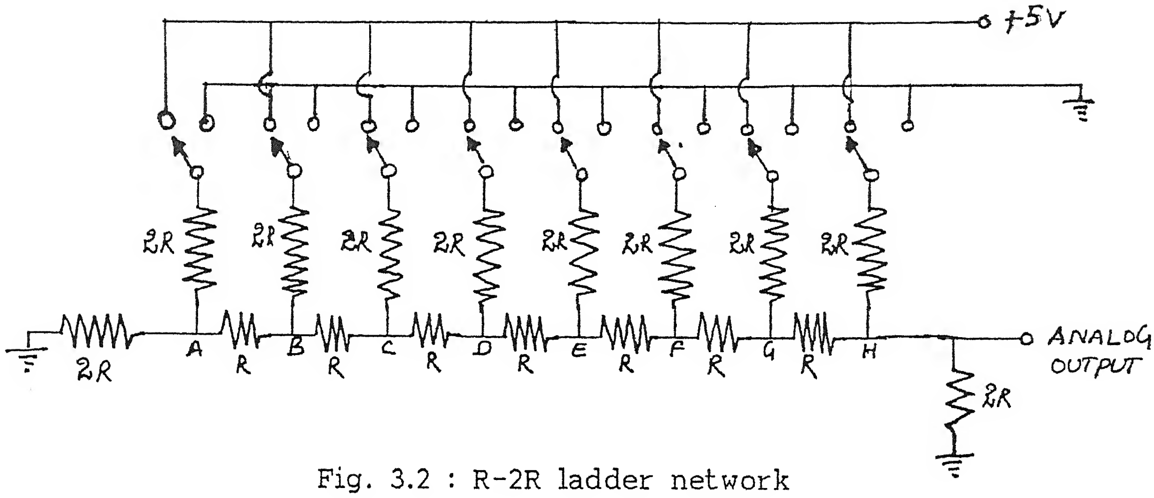


Fig. 3.2 : R-2R ladder network

At the left most node (A) the total resistance looking into the terminating resistor is 2R. The total resistance looking out towards the 2^0 input is also 2R. These two resistors can be combined to form an equivalent resistance of value R. At node B the resistance looking into the node A is 2R which is same as the total resistance looking out toward 2^1 input. These two resistors combined give a total resistance of value R. Similarly at other nodes also, the total resistance looking from any node back toward the terminating resistor or out toward the digital input is 2R. The total resistance at the rightmost node (H) will be 2R in parallel with a 2R resulting in a total resistance value R. To keep the ladder in perfect balance and to maintain symmetry the output of the ladder is terminated in a resistance of value 2R. This ensures that the input resistance to the ladder seen by each digital voltage source is constant. Due to the terminating resistance the resistance looking into any branch from any node has a value of 2R. Thus the input resistance seen by any input is 3R.

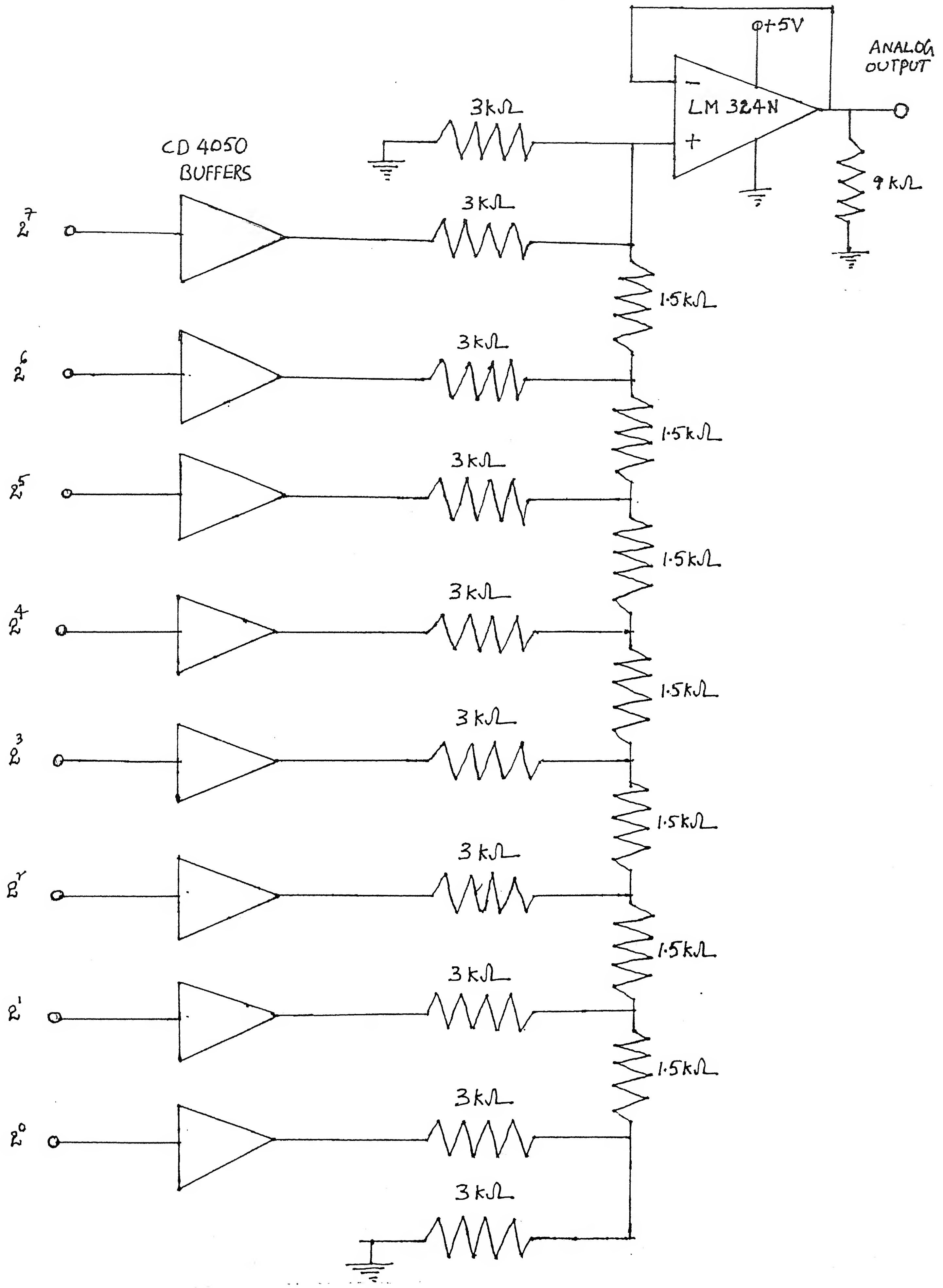


Fig. 3.3 :Digital to analog converter.

3.2.3 Theoretical analysis for D/A converter

For an 8 bit D/A converter the analog output voltage is given by

$$V_A = \frac{V}{3}\left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \frac{1}{128}\right)$$

(1) For 00001010 (10)

$$V_A = \frac{V}{3}\left(0 + 0 + 0 + 0 + \frac{1}{16} + 0 + \frac{1}{64} + 0\right) = 0.127 \text{ V}$$

(2) For 00010100 (20)

$$V_A = \frac{V}{3}\left(0 + 0 + 0 + \frac{1}{8} + 0 + \frac{1}{32} + 0 + 0\right) = 0.254 \text{ V}$$

(3) For 00110010 (50)

$$V_A = \frac{V}{3}\left(0 + 0 + \frac{1}{4} + \frac{1}{8} + 0 + 0 + \frac{1}{64} + 0\right) = 0.635 \text{ V}$$

(4) For 01100100 (100)

$$V_A = \frac{V}{3}\left(0 + \frac{1}{2} + \frac{1}{4} + 0 + 0 + \frac{1}{16} + 0 + 0\right) = 1.32 \text{ V}$$

(5) For 11001000 (200)

$$V_A = \frac{V}{3}\left(1 + \frac{1}{2} + 0 + 0 + \frac{1}{16} + 0 + 0 + 0\right) = 2.54 \text{ V}$$

(6) For 11111111 (255)

$$V_A = \frac{V}{3}\left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \frac{1}{128}\right) = 3.24 \text{ V}$$

where V = 4.88 V.

3.3 LED DRIVER CIRCUIT

A VCCS is used as an LED driver circuit for linear control of the current flow in LED.

Figure 3.4 shows the circuit diagram of LED driver circuit. It consists of a Darlington transistor pair for high gain and high input impedance. The LED is connected in the emitter circuit. The emitter circuit resistance R_E which is in series with the LED limits the current flowing it.

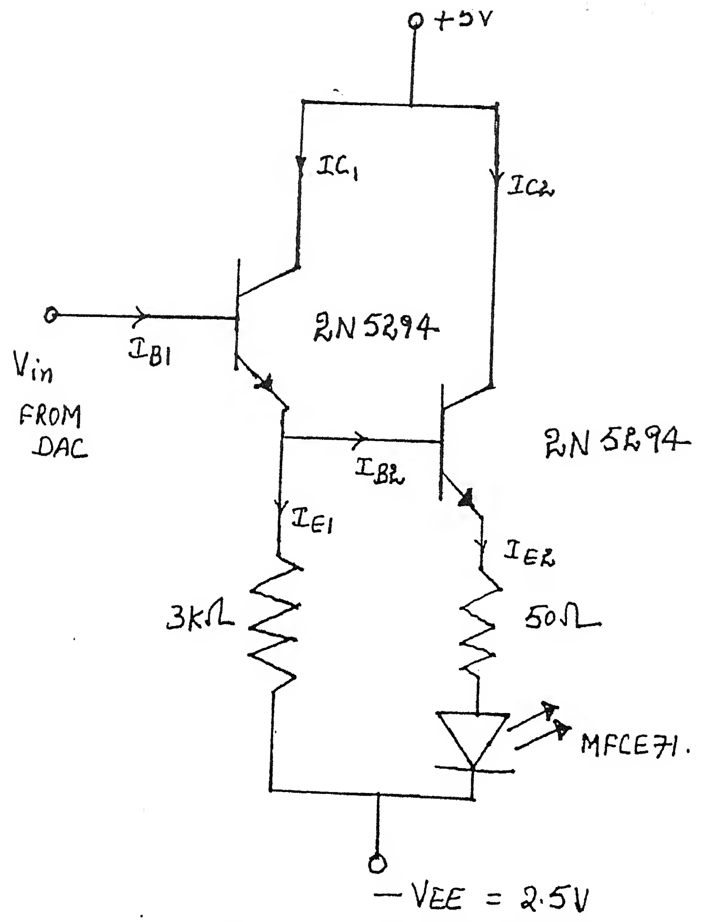


Fig. 3.4 : LED driver circuit

3.3.1 Analysis of the circuit

Both the transistors used in the Darlington pair were the same. Hence their DC current gains $\beta_1=\beta_2=50$ (approx.).

The base-emitter junction voltage $V_{BE1} = V_{BE2} = 0.7$ volts.

When the input voltage V_{in} to the transistor is zero the voltage at emitter $V_{E2} = 0 - (V_{BE1} + V_{BE2}) = -1.4$ volts. For $V_{in}=0$ the LED current must be zero. This requires can be satisfied by making $-V_{BE1} - V_{BE2} = V_{LED} + V_{EE}$, where V_{LED} is the forward biased voltage of the LED and V_{EE} is the negative supply in the emitter circuit. $V_{EE} = V_{E2}-I_ER_E$

Practically it is achieved by varying the voltage V_{EE} till the current through the LED is zero. Further when a voltage V_{in} is applied at the input. In general,

$$V_{E2} = V_{in} - (V_{BE1}+V_{BE2})$$

and the current through the LED is given by

$$I_{LED} = (V_{E2} - V_R)/R_E$$

i.e.,

$$I_{LED} = \frac{[V_{in} - V_{B1} - V_{BE2}] - [V_{LED} + V_{EE}]}{R_E}$$

Since $V_{LED} + V_{EE} = -V_{BE1} - V_{BE2}$

$$I_{LED} = V_{in} / R_E$$

Thus the current through the LED varies linearly with the input voltage.The above circuit independent of the β of the BJTs. However for small currents V_{BE1} and V_{BE2} be less than 0.7 volts. This will introduce nonlinearity for small currents. The LED used in this setup has a peak current of 60 mA. To prevent damage to the LED, the circuit tested up to a maximum I_{LED} Of 50 mA.

3.4 DETECTOR CIRCUIT

The circuit used for detection consists of a reverse biased photo diode in series with a resistance R_L. The value of resistance is in order of tens of KΩ. When the light output from the LED is incident on the upon the surface of the photo diode it produces a corresponding current which is a function of the responsivity of the photo diode. The output is taken across the resistance R_L.

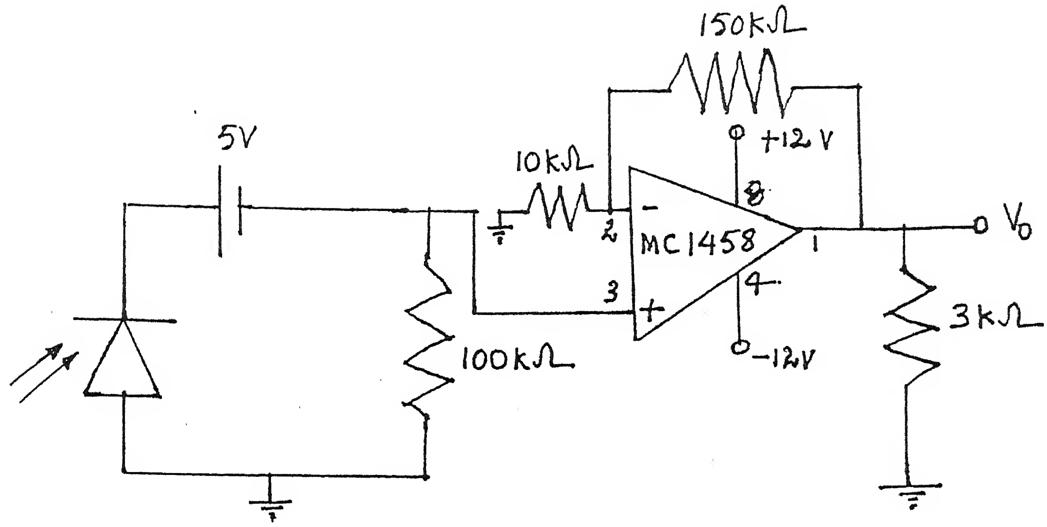


Fig. 3.5 : Detector circuit

The Current flowing through the detector circuit can be calculated using the drop across R_L. The drop across the resistor is amplified before applying to the ADC. The signal is amplified to keep the static noise to a minimum level by increasing the amplitude of the signal. The amplifier used here is an non-inverting amplifier with a gain of around 15. This is an high input impedance amplifier .

3.5 ANALOG TO DIGITAL CONVERTER

Analog to digital converters are used for converting the analog input to a corresponding digital data. Various circuits are available for executing analog to digital conversion. The selection of the circuit depends on speed, accuracy, cost, size and resolution required. In this system, PCL-205 Analog/Digital, I/O card has been used as an A/D converter which uses the principle of successive approximation. The successive approxima-

tion method of A/D conversion is capable of both high resolution as well as high speed. Each conversion is independent of the results of previous ones and the conversion time is constant and independent of the magnitude of the input voltage. The PCL-205 card consists of an ADC input channel and has a 12 bit resolution, 30 μsec conversion time and with an accuracy of ±0.5 % at 25^{O}C. And this card consists of two DAC output channels with 12 bit resolution, 5 μsec settling time with an accuracy of ±0.5% at 25^{O}C. It can support 16 single ended analog inputs with input range from -5 to +5 V, 16 digital inputs and 16 digital outputs. The analog output range is 0 to 5 V. It also has 3 channels of 16 bit programmable timer/counters.

For this thesis work, photo detector characteristics are plotted using the following procedure. According to the input data applied to digital to analog converter from parallel port of PC (input data is incremented in steps of LSB from 00000000 to 11111111) a corresponding voltage drop developed across the detector load resistor R_L. The current flowing through the diode is calculated using this voltage drop. A test detector and LED are placed so close together, and detector is assumed to be a broad band detector so that all the light emitted from the LED coupled to the detector. Responsivity of this test detector is calculated using the relation current flowing through the detector by power incident on the surface of the photo detector. Another detector is taken which is assumed to be having the same responsivity of broad band test detector. From responsivity and photo current flowing through the detector optical power incident on the photo detector

is calculated. Detector characteristics are plotted between optical power input versus current flowing through the detector.

CHAPTER IV

RESULTS. DISCUSSION AND CONCLUSIONS

4.1 RESULTS

Using the automated set up for the characterization of the the fiber optic detectors,following charecteristic curves plotted and analyzed.

i) DAC CHARACTERISTICS

Fig. 4.1 shows the DAC characteristic curve plotted between digital input data (decimal equivalent) with corresponding analog voltage output. There is some non linearity near decimal equivalent of binary 120 region and the reason for this non linearity is not clear.

ii) LED DRIVER CHARACTERISTICS

The LED driver (VCCS) characteristics are shown in the Fig. 4.2. The curve is plotted between the input voltage applied to the driver circuit and corresponding output current measured through the LED (source). Near the origin we observe non linearity.

iii) OVER ALL SYSTEM CHARACTERISTICS

Fig. 4.3 shows the over all automated system characteristics plotted between the digital input (decimal equivalent) against the detector output voltage(μw).The curve is non linear in lower as well as in the middle regions.

iv) LED CHARACTERISTICS

Fig. 4.4 shows the characteristic curve plotted between power output (μw) against the current flowing through the LED (mA). The curve has non linearity in the lower regions.

v) LED POWER OUTPUT Vs DETECTOR CURRENT

Fig 4.5 shows the characteristic curve plotted between LED power output (μw) versus detector current (mA). We can calculate the responsivity of the detector using this graph,assuming the detector has a broad area,and all the power emitted by the LED coupled to the detector.Except lower and high regions the curve was almost linear.

vi) DETECTOR CHARACTERISTICS

Fig 4.6 shows the detector characteristics plotted between detector current (μA) and power input to the detector (μw) Except in the lower and middle regions the curve is almost linear.

4.2 DISCUSSIONS

Almost all the curves plotted above are having non linearities in the lower and middle regions. The cause for non linearity is due to nonlinearity of sub systems like digital to analog converter, LED driver circuit etc. The cause of non linearityin the DAC has not been identified. In the case of LED driver circuit the nonlinearity is due to the D.C current gain of the transistor used at higher current levels and at lower current levels ,base emitter voltages of the trasistors are asummed to be 0.7v but practically this voltage is less.

4.3 CONCLUSIONS

Automated setup is useful for plotting the characteristic curves of the sources and detectors, if the nonlinearities in the aresystem eliminated.

-It reduces significantlythe time consumed in plotting the characteristics manually.

-Automated measurement gives accurate readings compared to manual plotting because errors like parallax etc are avoided.

-For plotting of characteristic curves coupling loss has not been taken into account, for more accurate curves this factor should be considered.

-Here we try to plot only power Vs current or linearity characteristics with some modification in the system it is possible to plot other characteristics.

REFERENCES

[1] Steward D. Personick, "Fiber Optics Technology and Applications", Khanna Publishers, Delhi, 1989.

[2] Charles K. Kao, "Optical Fiber Systems, Technology, Design and Applications", McGraw Hill Book Company, Inc.

[3] Gerd Keiser, "Optical Fiber Communications", McGraw Hill Book Company, Inc., 1991.

[4] Dennis Roddy, John Coolen, "Electronic Communications", Prentice Hall of India Pvt. Ltd., New Delhi, 1992.

[5] Rober G. Seippel, "Optoelectronics", Reston Publishing Co. Inc., Verginia, 1981.

[6] John M. Senior, "Optical Fiber Communications : Principles and Practice", Prentice Hall of India Pvt. Ltd., New Delhi, 1994.

[7] Albert Paul Mallvino, "Digital Computer Electronics : An Introduction to Computers", Tata-McGraw Hill Publishing Co. Ltd., New Delhi, 1983.

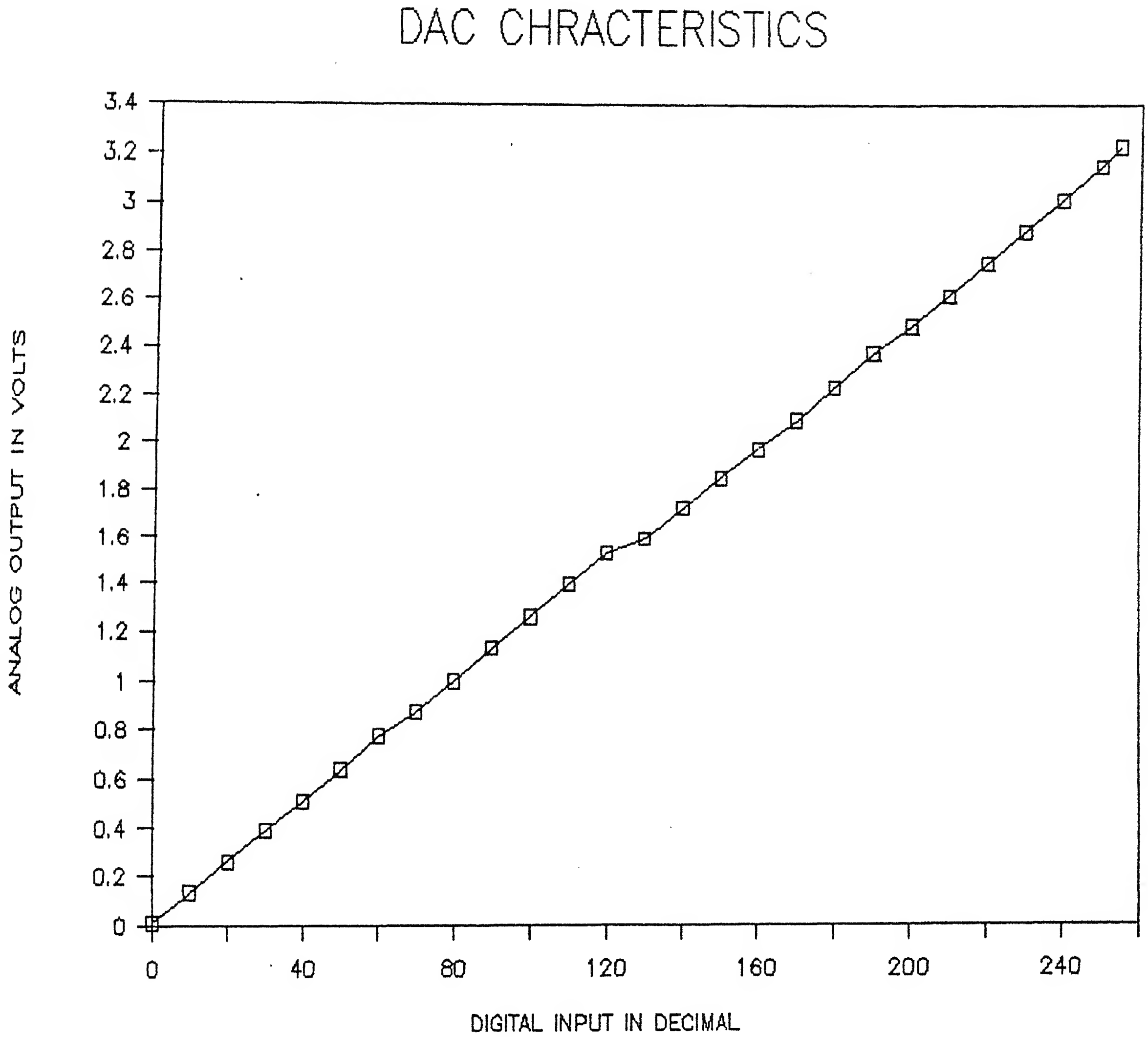


FIG. 4.1 : DAC CHARACTERISTICS

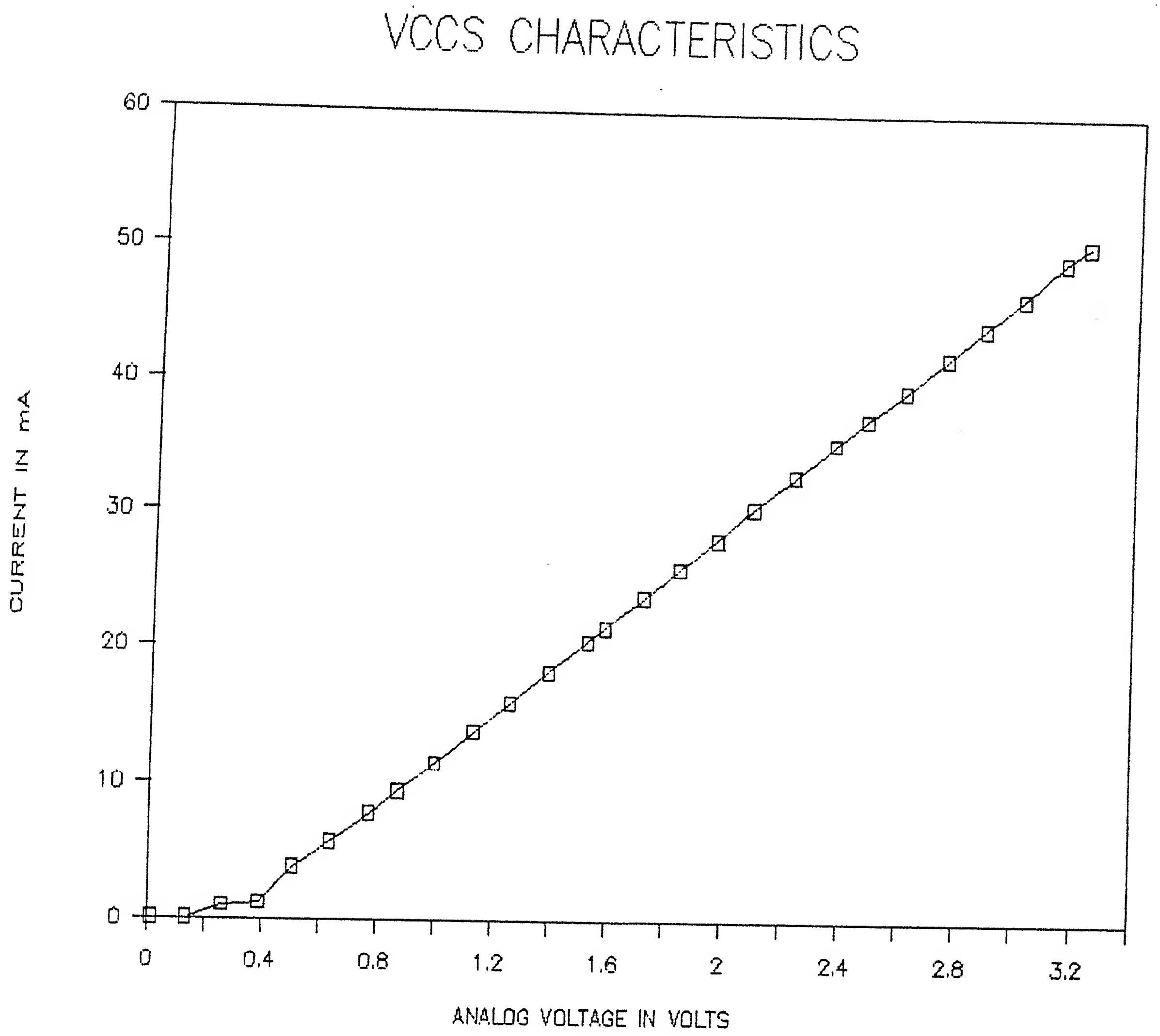


FIG. 4.2 : VCCS CHARACTERISTICS

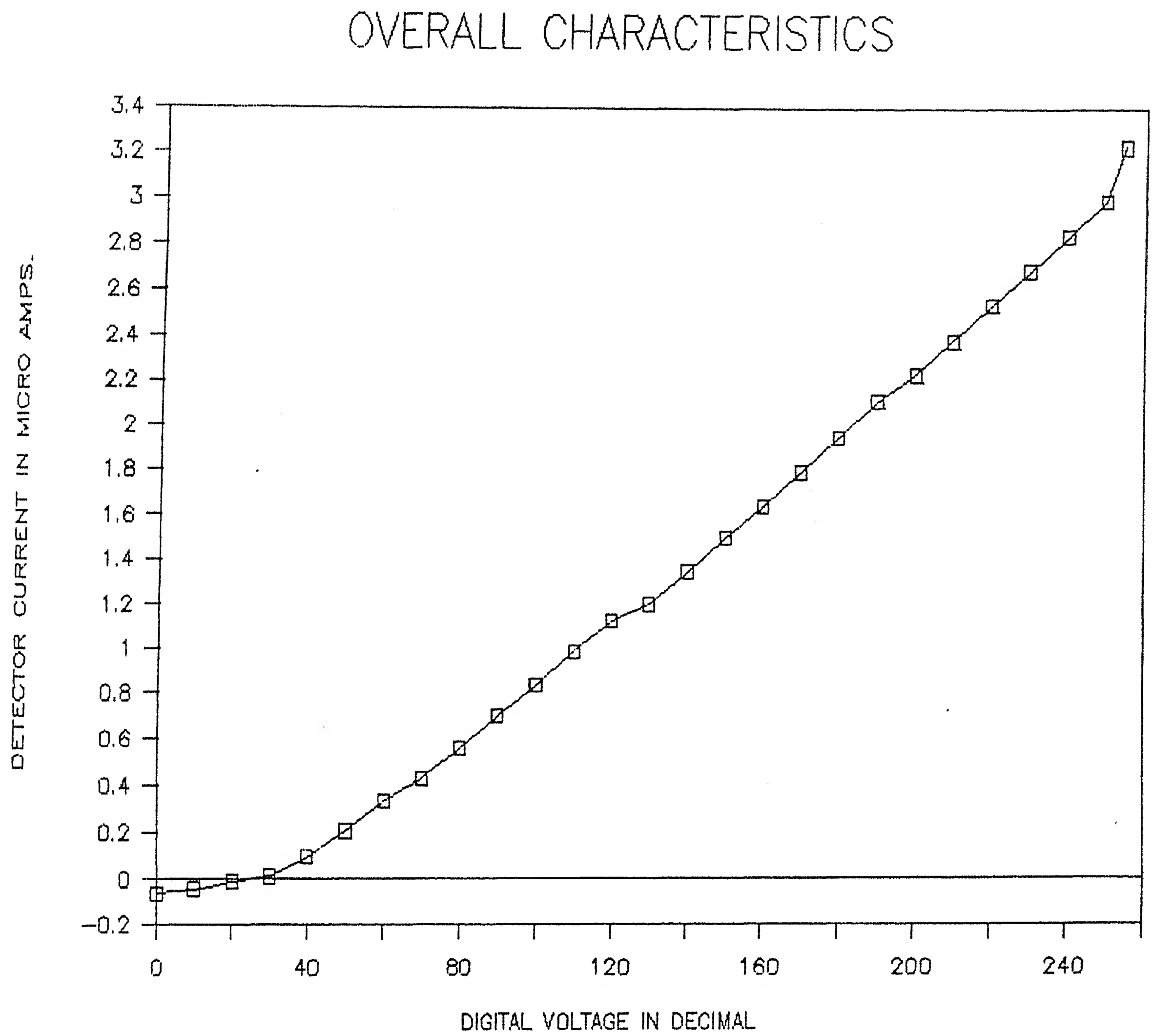


FIG. 4.3 : OVERALL CHARACTERISTICS

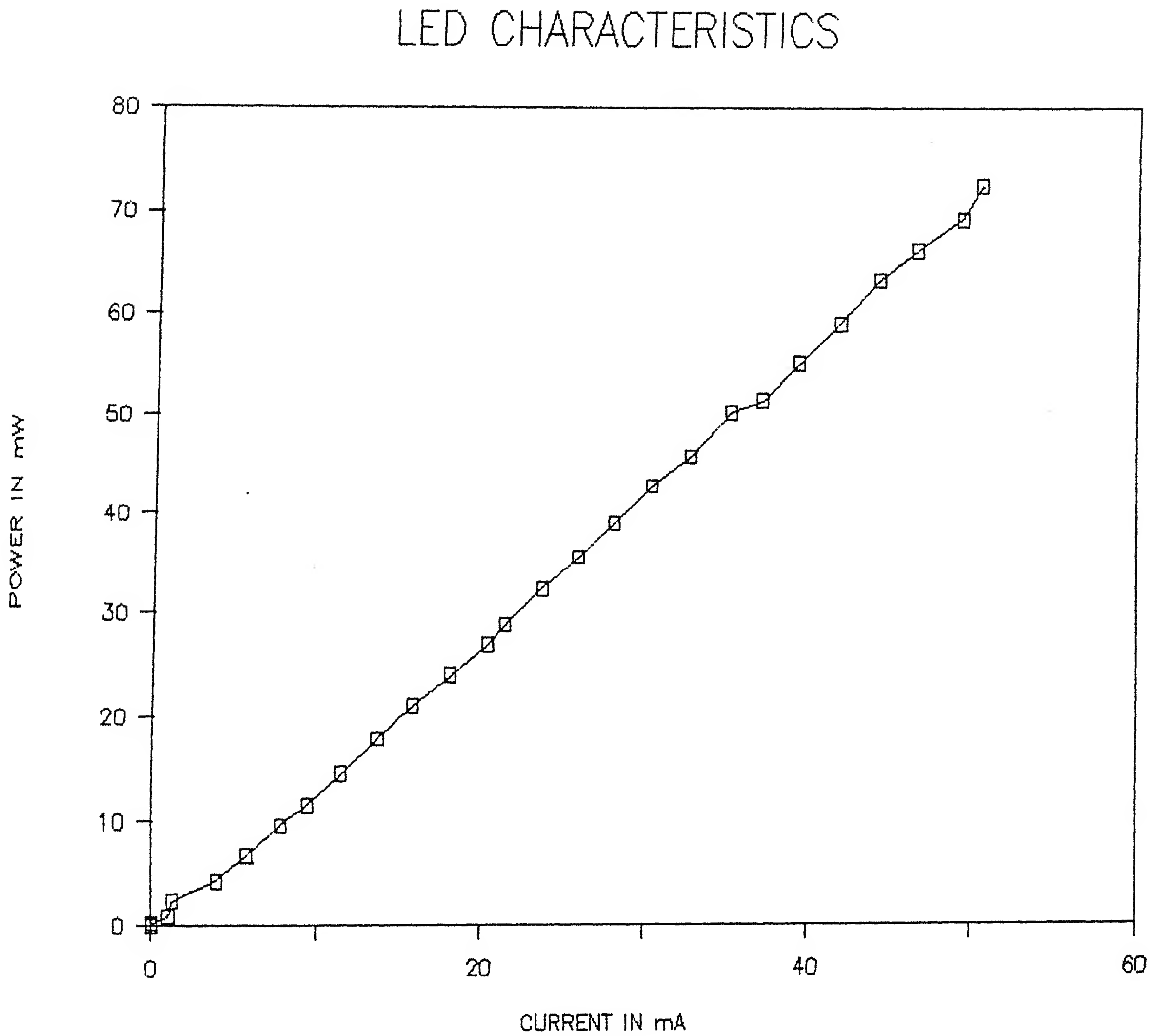
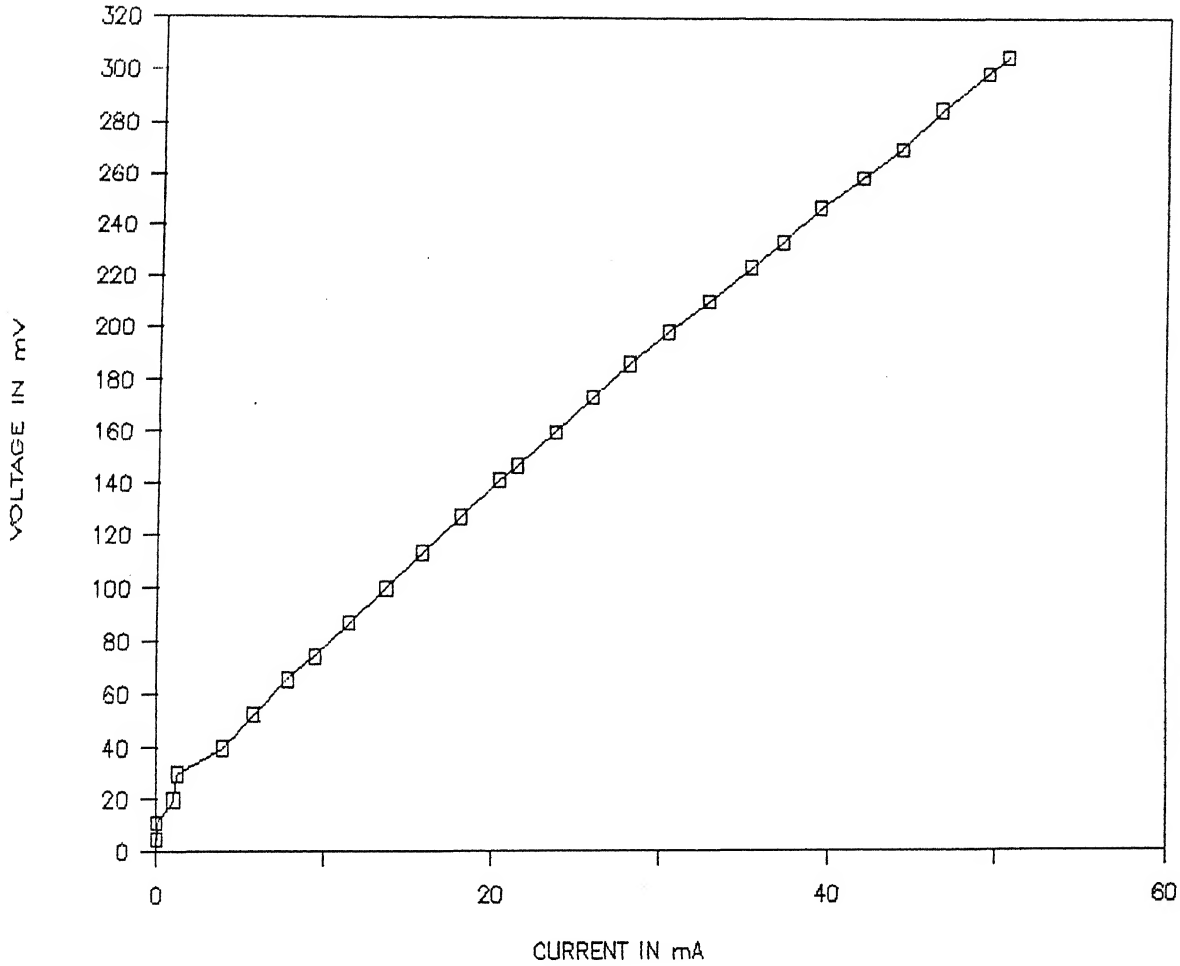


FIG. 4.4 : LED CHARACTERISTICS

LED CURRENT VS DETECTOR VOLTAGE



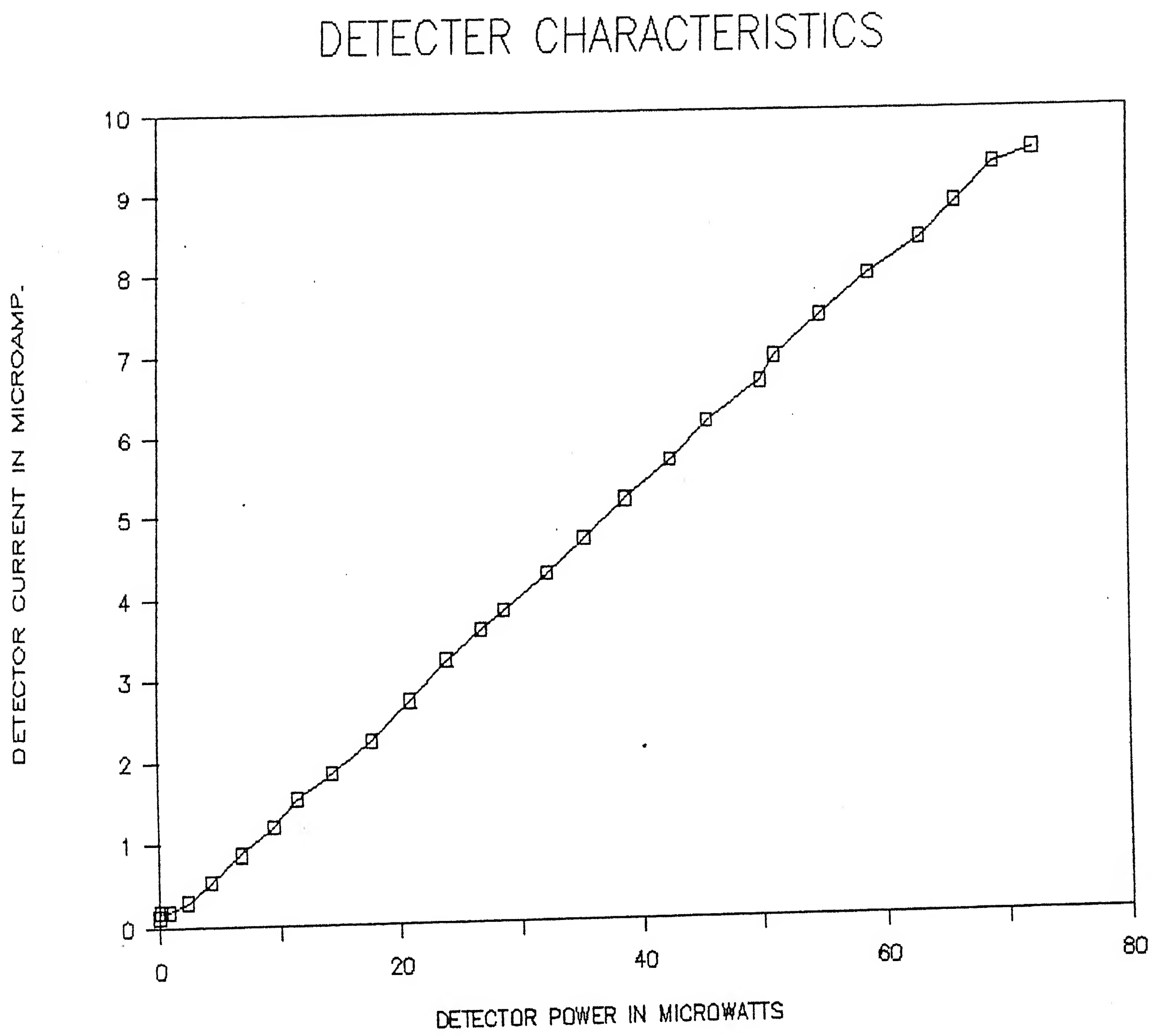


FIG. 4.5 : LED POWER OUTPUT VS DETECTOR CURRENT

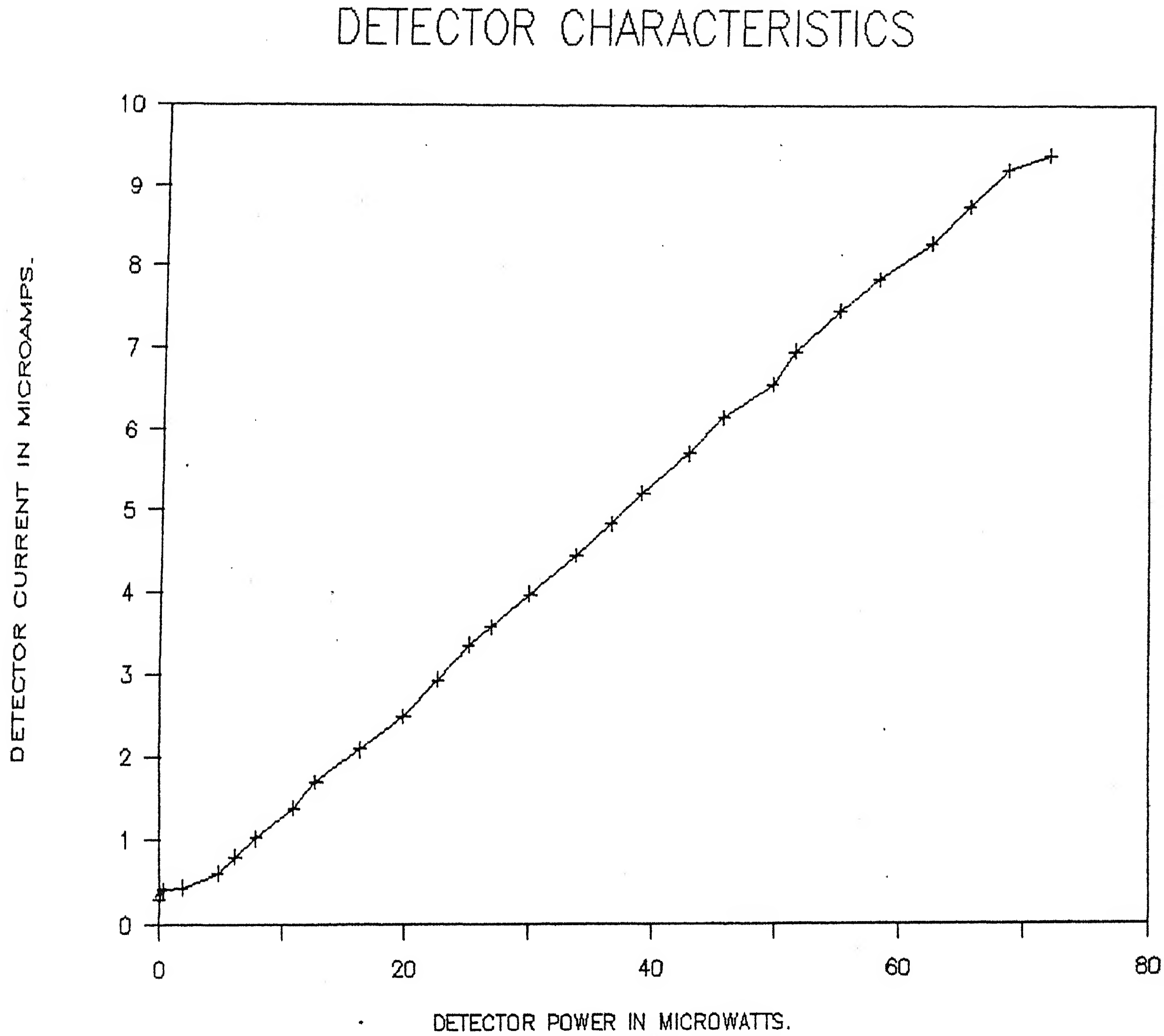


FIG. 4.6 : DETECTOR CHARACTERISTICS